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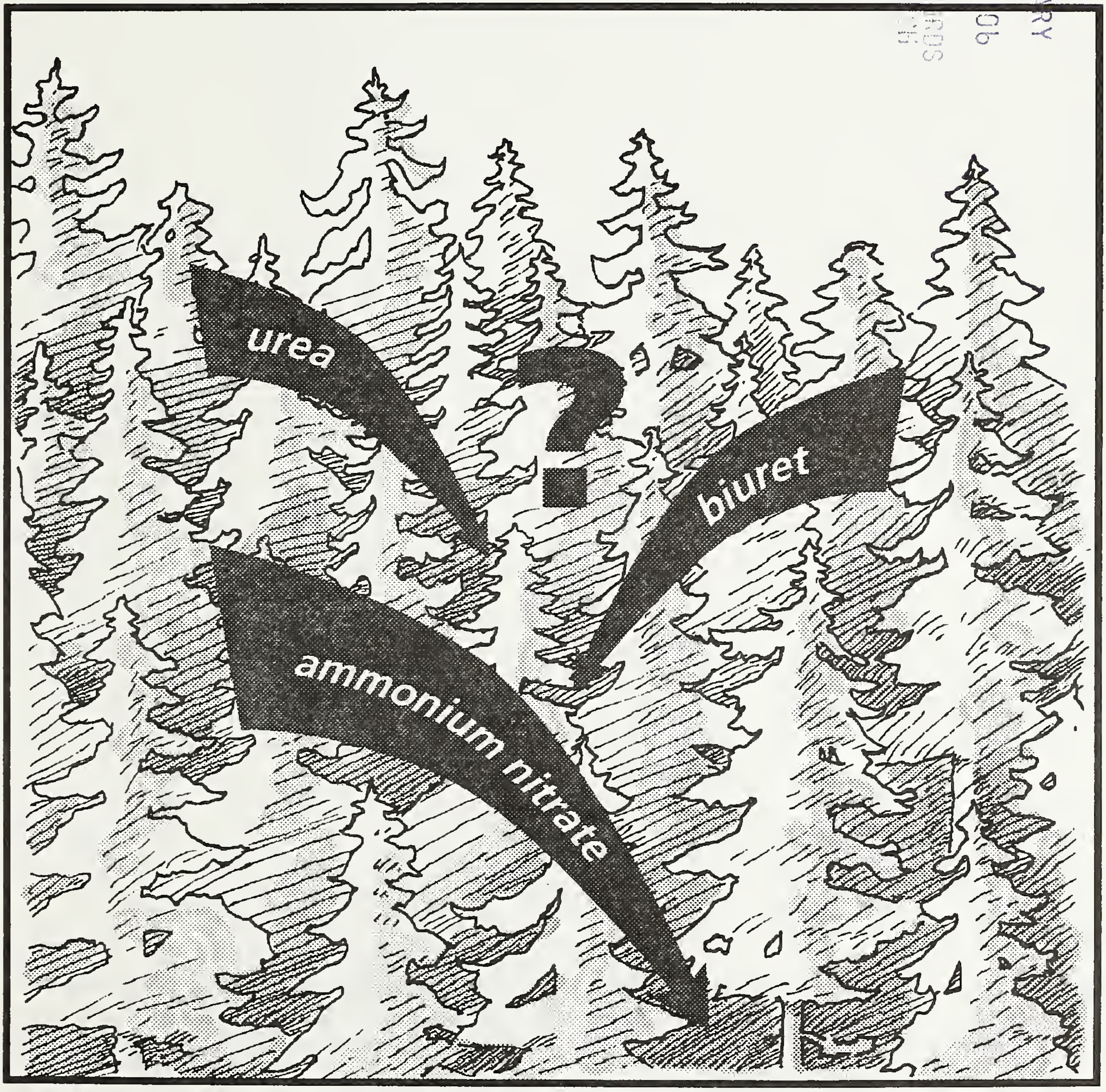
Ammonium Nitrate, Urea, and Biuret Fertilizers Increase Volume Growth of 57-Year-Old Douglas-Fir Trees Within a Gradient of Nitrogen Deficiency

Richard E. Miller, Donald L. Reukema, and John W. Hazard



Authors

RICHARD E. MILLER is a research soil scientist and DONALD L. REUKEMA is retired, Pacific Northwest Research Station, 3625 93d Avenue SW, Olympia, WA 98512-9193; and JOHN W. HAZARD is a biometrician, Statistical Consulting Services, Bend, OR 97701.

Abstract

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In a nitrogen-deficient plantation in southwest Washington, we (1) compared effects of 224 kg N/ha as ammonium nitrate, urea, and biuret on volume growth of dominant and codominant Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco); (2) determined how 8-year response of these trees to fertilization was related to their distance from a strip of the plantation interplanted with nitrogen-fixing red alder (*Alnus rubra* Bong.); and (3) observed effects of biuret on understory vegetation. On both sides of the strip centerline, we grouped subject trees into 30 plots of 4 trees each, based on slope position and distance from alder. We randomly assigned three fertilizers and a control within each plot. We analyzed separately data from east and west of the mixed stand centerline. Initial volume differed greatly among the 120 trees on each side, so we used covariance analysis to adjust observed treatment means. Adjusted mean volume growth was increased ($p \leq 0.10$) by 22 to 28 percent on the east side and by 11 to 14 percent on the west side, with no significant difference in response to the three fertilizers. Only biuret stimulated growth within the mixed stand. Biuret had no visible toxic effect on competing vegetation during 8 years after application.

Keywords: *Pseudotsuga menziesii*, Douglas-fir, *Alnus rubra*, red alder, nitrogen fertilization, biuret, ammonium nitrate, urea, volume growth.

Summary

Urea is the most commonly used source of nitrogen (N) for fertilizing Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) forests in the Pacific Northwest. Although ammonium nitrate is an alternative source, about 20 percent more gain in cubic volume growth would be necessary to offset its greater treatment cost (material plus spreading). A third potential source is biuret from which nitrogen is released more slowly than from urea and, especially, from ammonium nitrate. Although biuret is toxic to most agricultural plants, some coniferous tree species, including Douglas-fir, tolerate biuret and respond positively in seeding size and weight. We report the first comparison of biuret versus other conventional sources of nitrogen under field conditions. The scope of our comparison was restricted to an N-deficient plantation in southwest Washington. At the time of fertilization, this 57-year-old plantation still retained most of the trees originally planted at a 2.4- by 2.4-m spacing after the 1928 growing season. Douglas-fir numbers were fewer, but volume of individual dominant trees averaged about 2.6 times greater, in a 27-m-wide strip through the plantation that had been interplanted at year 4 with N-fixing red alder (*Alnus rubra* Bong.). We surveyed a 15- by 15-m grid east and west of the mixed stand and selected the largest undamaged Douglas-fir closest to each grid point as our subject trees. The 240 subject trees were either 15, 30, 45, or 60 m from the outer row of red alder or within the mixed stand (0 m). At each of these distances, we randomly assigned one of four treatments (urea, ammonium nitrate, biuret, or control) to each tree. Dosage was 224 kg N/ha for each fertilizer. After adjustment of subsequent 8-year volume growth for differences in mean initial tree size among the four treatments, response (mean volume growth per tree) to the three fertilizers was similar. We had expected that biuret might promote tree growth by retarding growth of competing vegetation; however, we observed no foliage discoloration or depressed growth of any native plants, including locally prevalent salal (*Gaultheria shallon*), Oregongrape (*Berberis* sp.), and bracken fern (*Pteridium aquilinum* (L.) Kuhn.). Hence, 224 kg N/ha as nearly pure biuret was not toxic to these native plants and associated Douglas-fir during our 8-year period of observations. Within the mixed stand, adjusted response to N-fertilization was minimal (10 percent with biuret and zero with ammonium nitrate and urea) and statistically nonsignificant. Nearly pure biuret was the only N-source that seemed to stimulate growth within the mixed stand, but we have no explanation for this. The strong response to fertilization at 15 m and farther from the mixed stand indicated that red alder was not providing sufficient N for improved Douglas-fir growth at 15 m or greater distance. Although response to more soluble ammonium nitrate was slightly faster than response to urea and biuret, continued preference of land managers for the cheapest N-source, urea, is justified.

Introduction

In about 70 percent of tested Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco) stands in western Oregon, Washington, and British Columbia, tree growth was increased by nitrogen (N) additions (Miller and others 1986). Urea was the N-source in nearly all trials. To evaluate cost-effectiveness of other N-sources, we compared three N-fertilizers at an N-deficient site in southwest Washington. Previous research shows that both red alder (*Alnus rubra* Bong.) (Miller and Murray 1978, Miller and others 1993, Tarrant 1961) and ammonium nitrate (AN) fertilizer (Miller and Tarrant 1983) enhance long-term growth in this 1928 Douglas-fir plantation in the Wind River Ranger District, Gifford Pinchot National Forest, near Carson, Washington.

Ammonium nitrate is not used conventionally to fertilize Northwest forests. Of the nearly 0.8 million ha of Douglas-fir forests operationally fertilized since 1966, only about 200 ha were fertilized with AN; the balance were fertilized with less expensive urea. In the few trials where AN and urea have been compared, response to AN equals or exceeds that for urea (Dangerfield and Brix 1981, Harrington and Miller 1979, Miller and Reukema 1974, Opalach 1987). At some locations, however, neither AN nor urea provided measurable response (Miller and others 1986). For AN to be competitive in price with urea, about 20 percent more gain in cubic volume growth would be necessary to offset higher treatment cost (material plus spreading).

Biuret, an inherent contaminant of urea fertilizer, is a potential source of nitrogen. Biuret consists of two urea molecules fused when very high temperature is attained during the urea manufacturing process. Although biuret is toxic to most agricultural plants, species differ in their susceptibility to injury from biuret (Commonwealth Agricultural Bureaux 1977). Toxic effects of biuret closely resemble those of high concentrations of free ammonia or nitrite, which also can occur after urea application to soil (Kilmer and Englestad 1973). Some coniferous tree species tolerate biuret and respond positively in size and weight. Growth of potted Douglas-fir and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) seedlings was stimulated by the equivalent of 45 kg biuret/ha (18 kg N/ha) (Miller and others 1988). Moreover, dosages up to 560 kg biuret/ha (224 kg N/ha) enhanced growth of redwood seedlings (*Sequoia sempervirens* (D. Don) Endl.) in a tree nursery in northern California.[1]

Biuret is a potential slow-release source of N that has not been tested in forest stands. To be a cost-effective substitute for conventional urea fertilizer, however, at least 35 percent more gain (response/kg N) would be needed to offset additional costs of manufacturing (20 percent) and application costs (15 percent). This assumes direct manufacture of biuret, which would be cheaper than reheating urea prill, and lower N-content of biuret (ca. 40 percent) vs. that for urea (46 percent).

The objectives of the research were to:

- Compare effects of three fertilizers (AN, urea, and biuret vs. untreated control) on volume growth of individual dominant and codominant Douglas-fir. Determine if response to slow-release biuret is delayed relative to more rapidly released AN.

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[1] Personal communication. 1983. Don Young, research chemist, Union Oil Research, Brea, CA.

- Determine to what extent response of these trees to N-fertilization differs with distance from a mixed Douglas-fir/red alder stand. Presumably, response to fertilizer at a given distance would indicate that red alder is not providing adequate N at that distance.
- Observe effects of biuret on vegetation beneath fertilized trees. Reduced growth or death of competing vegetation could enhance tree growth.

Methods

Site Description

Elevation of this low-productivity study area is 530 to 620 m. The topography is moderately dissected, although nearly all the study area has a north-northeast aspect (fig. 1). Slopes within the study area range from 2 to 40 percent. Annual precipitation averages 2540 mm, with 10 percent falling in the frost-free growing season of about 130 days (Pacific Northwest River Basins Commission Meteorology Committee 1969). Wildfire swept the area in 1902 and 1927. The soil, a moderately deep, well-drained gravelly loam derived from pyroclastic rocks, contained about 3000 kg/ha of total N to a 0.91-m depth at stand age 30 (Tarrant and Miller 1963).

Stand Description

The plantation was started after the Yacolt Fire of 1927. Two-year-old Douglas-fir from an unknown, nonlocal seed source were planted on several thousand acres at a 2.4- by 2.4-m spacing after the 1928 growing season. Four years later, 2-year-old red alder seedlings were interplanted at a 1.8- by 1.8-m spacing to create a 27-m-wide strip through a portion of this Douglas-fir plantation; the mixed-species strip straddled a north-south section line for about 1000 m. These alder also originated off-site from seed collected at 15-m elevation near Olympia, Washington. At the start of this fertilization study in 1984, Douglas-fir in the mixed-species strip were much larger than those outside the strip (Miller and others 1993).

Survey and Fertilization

We surveyed a 15- by 15-m grid east and west of the mixed stand and selected the undamaged dominant or strong codominant Douglas-fir closest to each grid point (fig. 1). We designated Douglas-fir closest to and parallel to the outermost row of alder as column I. All these Douglas-fir were within the drip-line of alder crowns and most were inside the mixed stand. Trees in columns II-V were 15, 30, 45, and 60 m, respectively, from the outer row of alder. We extended 24 east-west rows on each side of the mixed stand, thus selecting a total of 240 study trees (5 trees by 48 rows). The scope of the conditions measured at this study area are limited; hence, inferences should not be made beyond this area. The uniqueness of this area, however, provided the opportunity to meet our objectives.

Fertilizer treatments were assigned after grouping the 24 east-west rows on each side of the mixed-stand centerline by fours (fig. 1). For example, on the east side, rows 1-4 are slope position 1 (=block 1 and highest on the slope), rows 5-8 are block 2, and so forth. Each slope position and distance (column) combination included four trees. We randomly assigned one of four fertilizer treatments (control, AN, urea, or biuret) to each tree.

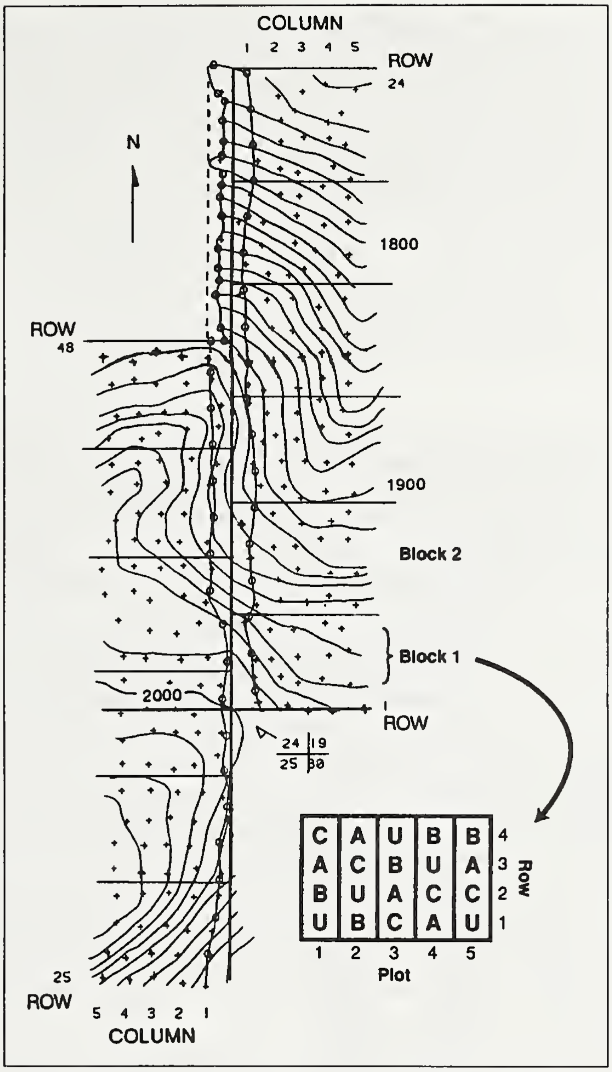

Figure 1—Topography, tree location, and illustrative arrangement of plots within blocks in the study area. Contours give elevation in feet (1 ft = 0.3048 m); + = measured trees located on a 15- by 15-m grid; and edge of mixed stand designated by small circles. Treatments are A = ammonium nitrate, B = biuret, U = urea, and C = control.

We uniformly spread fertilizer within a 3.6-m radius from subject trees. This 0.004-ha area usually included the base of the four closest competitors to each subject tree, yet maintained adequate distance between adjacent subject trees so their treatments were independent. We applied fertilizers on 17 April 1984. Cool weather and rains followed this date, so volatilization losses were unlikely. The amount of fertilizer per tree to provide 224 kg N/ha was:

Fertilizer	N	Fertilizer
	Percent	*Kilograms*
Urea	46	1.97
Ammonium nitrate	34	2.67
Biuret[2]	36.8	2.47

Tree Measurement

We measured diameter at breast height (d.b.h.) to the nearest 2.5 mm, and height to the nearest 0.30 m, after the 1983 growing season. We remeasured d.b.h. and height of the 240 subject trees after the 1985, 1987, 1989, and 1991 growing seasons. We estimated inside-bark bole volume, including stump and tip, by entering tree d.b.h. and height in a Douglas-fir volume equation (Bruce and DeMars 1974).

Statistical Design and Analysis

We based the format of our statistical analysis on (1) the experimental questions and (2) the way we selected experimental units (subject trees) and assigned fertilizer treatments. On both sides of the mixed alder/Douglas-fir stand, we grouped subject trees into blocks based on slope position (rows) and into plots based on distance from alder (columns). This provided 6 blocks by 5 distances, or 30 plots of 4 trees each on each side (fig. 1). These plots were not randomly located but were fixed locations (whole plots), within which four fertilizer treatments were randomly assigned to individual trees. Fertilizer effects were compared by a set of orthogonal contrasts (that is, control vs. the average of all fertilizers, AN vs. biuret+urea, and biuret vs. urea). These contrasts supported inferences about the effectiveness at this location of (1) three N-fertilizers in general, (2) more rapidly soluble AN-fertilizer compared to the average of two urea-based fertilizers, and (3) conventional urea vs. biuret, a slow-release derivative of urea.

We analyzed data from east and west of the mixed stand separately because the two sides are fixed (not random) locations, with about a 3-percent downhill gradient from the west to east. The experimental design is a randomized block, with blocks corresponding to slope position. Whole-plot treatments were distances from the mixed stand, and split-plot treatments were fertilizer applications. In these analyses, a p-value ≤ 0.10 was used to judge statistical significance of differences. Finally, by pooling data from subject trees within the mixed stand (column 1 trees of both east- and west-side sets), we performed a conditional test to indicate fertilization effects within the mixed stand. We recognized that by reusing portions of the data from the original analyses, probability levels of the tests of hypothesis could be biased. To reduce type I error, we used $p \leq 0.05$ to judge significance in this test.

[2] UNOCAL Research and Technology (Brea, CA) made and provided this fertilizer containing 87.8 percent biuret and 12.2 percent triuret. The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Results

Tree Size Before Fertilization and Unadjusted Growth

Before fertilization, the largest trees were located within the alder strip, demonstrating the benefits of N-fixation at this location, but also inflating variation in tree size within fertilizer treatments. Coefficients of variation in tree volume ranged from 55 to 91 percent among the treatments (table 1). Trees east of the alder strip averaged larger diameters, heights, and volumes (table 1) than those to the west. Despite randomization, control trees on the west side averaged 13 to 31 percent smaller than treated trees (table 1). Mean volume of control trees on the east side, however, averaged 11 percent smaller to 31 percent larger than the mean volume of fertilized trees. Although initial inspection of the data suggested that average tree volume among the four treatments may have differed before fertilization, analysis of variance did not confirm this suspicion on either the east ($p = 0.34$) or the west side ($p = 0.58$).

Without adjustment, 8-year volume growth of fertilized trees consistently exceeded that of control trees by 10 to 42 percent (table 1). We hypothesized, however, that differences in growth would be related to initial size; therefore, we attempted to remove some of the effect of differing initial size by expressing average annual growth of each tree in the 8-year period as a percentage of initial size. This indicated that average annual increase of fertilized trees was 23 to 42 percent more than corresponding control trees (table 1).

Table 1—Average tree volume and 8-year volume growth, by side or direction from the mixed stand, and treatment

Side	Treatment[a]	1983 volume[b] CVTS	1983 volume[b] CV	Total 8-year growth Observed	Total 8-year growth Adjusted[c]	Average annual increase (observed)[d]
		m^3	*Percent*	*m^3*	*m^3*	*Percent*
East	AN	0.679	59	0.319	0.340	6.1
	U	.865	77	.384	.345	6.0
	B	.669	68	.302	.327	5.6
	C	.764	55	.275	.269	4.3
West	AN	.602	87	.252	.233	5.4
	U	.518	85	.223	.232	5.4
	B	.594	91	.255	.238	5.5
	C	.458	77	.180	.209	4.4
		Relative to control (control = 100)				
East	AN	89		116	126	142
	U	113		140	128	140
	B	88		110	122	130
West	AN	131		140	111	123
	U	113		124	111	123
	B	130		142	114	125

[a] AN = ammonium nitrate; U = urea; B = biuret; C = control.
[b] CVTS = Cubic volume total stem, including tip and stump; CV = coefficient of variation.
[c] Average 8-year volume growth in each treatment was adjusted by covariance for differences among the treatments in initial (1983) volume. Slopes were homogeneous ($p \leq 0.68$).
[d] Computed by averaging the percentage increase for individual trees at each treatment.

Table 2—Degrees of freedom, mean squares, and p-values from analysis of covariance of 8-year volume growth, east and west sides

Source of variation[a]	D.f.	East side M.s.	East side P-value	West side M.s.	West side P-value
Main plot:					
Regression	1	0.204	0.00	0.218	0.00
Block (slope position)	5	.011	.58	.001	.95
Distance—					
Linear	1	.045	.09	.060	.00
Quad.	1	.004	.59	.024	.04
L. of f.	2	.030	.14	.001	.93
Error 1	19	.014	—	.005	—
Split plot:					
Regression	1	1.070	.00	.976	.00
Constant	1	.087	.00	.021	.02
Fertilizer contrast[b]—					
1 = C vs. F	1	.105	.00	.013	.05
2 = AN vs. U+B	1	.001	.84	.000	.91
3 = U vs. B	1	.004	.47	.001	.62
Interactions:					
Fert. by distance—					
Cont. 1 × linear	1	.000	.95	.015	.04
× quad.	1	.007	.34	.001	.53
× l. of f.	2	.011	.27	.006	.17
Cont. 2 × linear	1	.002	.67	.000	.99
× quad.	1	.001	.25	.001	.55
× l. of f.	2	.007	.41	.001	.65
Cont. 3 × linear	1	.021	.12	.019	.02
× quad.	1	.006	.41	.000	.96
× l. of f.	2	.026	.05	.001	.73
Error 2	74	.008	—	.003	—

[a] Contrast 1 = control vs. AN + U + B; 2 = AN vs. B; 3 = U vs. B.; l. of f. = lack of fit.
[b] C = control, F = fertilizer, AN = ammonium nitrate, U = urea, B = biuret.

Adjusted Growth and Response

Volume growth after 1983 was related positively to tree volume in 1983 and negatively to distance from alder. On the east side, this relation with distance was linear in the 8-year period (table 2). On the west side, growth had a quadratic relation with distance from the mixed stand.

East side—In the 8 years after fertilization, average adjusted volume growth of fertilized trees exceeded that of nonfertilized by 22 to 28 percent (table 1). Treatment-by-distance interactions were nonsignificant, indicating that average response to the three fertilizers was similar at all distances (contrast 1, table 2). Average response to AN did not differ from that response to urea or biuret (contrast 2, table 2). The inconsistency of response to urea vs. biuret within the N-gradient created by the mixed stand is indicated by a significant interaction (contrast 3 × lack-of-fit, table 2). Biuret was more effective than urea within the mixed stand and less effective at 60 m (fig. 2).

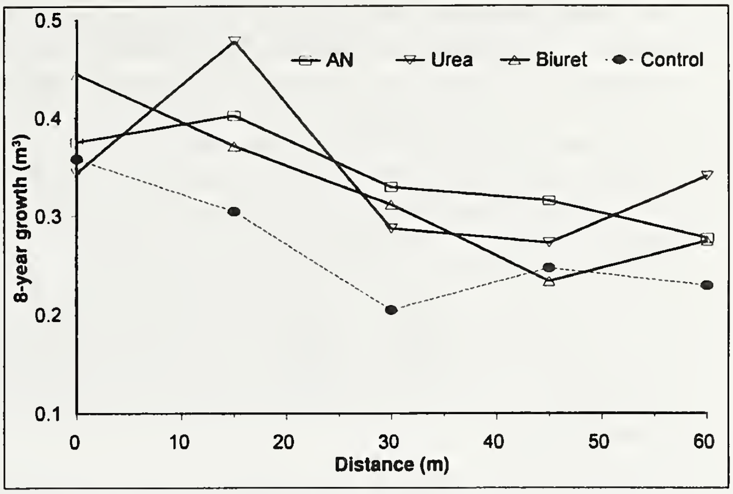

Figure 2—Average adjusted 8-year volume growth per tree by distance from stand and treatment, east side.

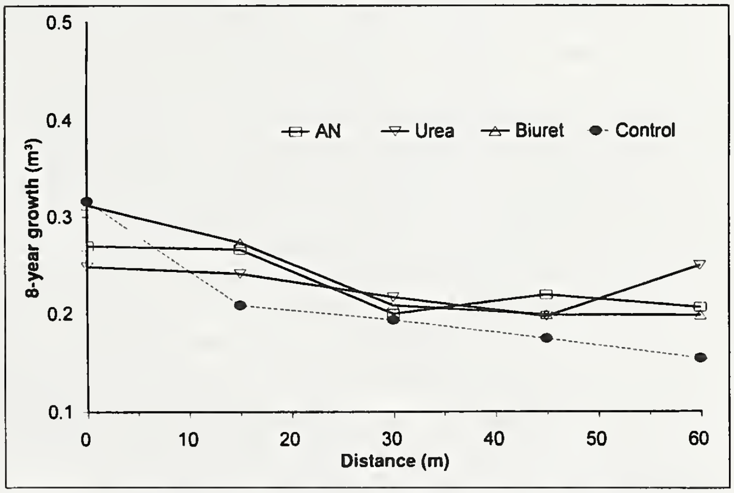

Figure 3—Average adjusted 8-year volume growth per tree by distance from mixed stand and treatment, west side.

West side—In the 8 years after fertilization, average adjusted volume growth of fertilized trees exceeded that of control trees by 11 to 14 percent (table 1). Response to N on the west side was about half that on the east side. Response to the three fertilizers increased linearly with distance from the mixed stand, as indicated by the significant contrast 1 × distance interaction (table 2). Figure 3 illustrates the lack of response within the mixed stand and the increasingly positive response between 15 and 60 m. Adjusted response to AN did not differ from that of urea and biuret; however, biuret was more effective than urea within west side of the mixed stand (contrast 3 × linear interaction, table 2).

Response within the mixed stand—Our analysis of the 8-year, east-side data indicated similar response to fertilization at all distances (table 2; fig. 2). In contrast, response to fertilization on the west side increased with distance from the mixed stand (table 2), and trends of adjusted means (fig. 3) showed no response within the mixed stand. We examined this inconsistency directly by pooling all column I trees (those within the mixed stand) and performing an additional covariance analysis. This is a conditional analysis because we re-used some data of the original analyses (table 2); therefore, probability levels may be biased. The ANOVA results suggest that fertilizers did not enhance growth of Douglas-fir trees within the mixed stand ($p = 0.41$, table 3). The interpretation of these results is clouded, however, because the 12 randomly assigned control trees averaged 17 percent smaller than fertilized trees (table 3). Covariance adjusted the means of observed growth for each treatment and likely prevented an incorrect interpretation about fertilizer effects in the mixed stand.

Discussion

Before fertilization, bole volume of these 57-year-old crop trees was clearly greatest within the mixed stand and decreased markedly with increasing distance into the pure Douglas-fir plantation. Additional details about initial tree size are provided in Miller and others (1993). Despite greater stem numbers and volume in the mixed stand (Miller and Murray 1978), Douglas-fir in the mixed stand were clearly larger than those in adjacent portions of the same plantation with no interplanted alder. Because of N-fixation, soil N-content in the mixed stand exceeded that in the pure stand by 750 kg/ha at age 30 (Tarrant and Miller 1963) and by 2400 kg/ha at age 52 based on an independent sampling protocol (Binkley and others 1992). Plant-available N (anaerobic-N) at age 60 averaged 33 mg/kg within the mixed stand compared with 17 mg/kg in the pure stand to the west side and 24 mg/kg to east (Rhoades and Binkley 1992). Because of the slight downhill slope to the east, the increased N-availability extended about 8 to 12 m into the pure stand on the east side. Although this nutrient gradient could have reduced response of position 2 trees on the east side to N-fertilizers, the 8-year data do not confirm this (fig. 2).

After adjustment of volume growth for differences in initial tree size among the four treatments, mean volume growth per tree, hence response, was similar for the three fertilizers. The ratio of growth, period 1:period 2, in the following tabulation generally shows relatively more growth in the second period:

	Mean east-side growth		Mean west-side growth	
Treatment	Total 8-year	Ratio P2:P1	Total 8-year	Ratio P2:P1[3]
	m^3		m^3	
AN	0.340	1.08	0.233	0.99
U	.345	1.20	0.232	1.13
B	.327	1.18	.238	1.09
O	.269	1.17	.209	1.23

The growth ratio for AN, however, was lowest of the four treatments on both the east side (1.08; $p \leq 0.07$) and west side (0.99; $p \leq 0.24$), thus suggesting more rapid response with it than with urea and biuret.

[3] Adjusted growth in years 5-8 ÷ growth in years 1-4.

Table 3—Degrees of freedom, mean squares, p-values, and adjusted means from analysis of covariance of 8-year volume growth within the mixed stand

					Total 8-year growth	
Source[a]	D.f.	M.s.	P-value	1983 volume	Observed	Adjusted[b]
			≤	*m^3(C=100)*	---- *m^3* ----	
Regression	1	1.439	0.01	—	—	—
Treatment	3	.016	.41	—	—	—
Error	43	.016	—	—	—	—
				Adjusted means		
AN	—	—	—	1.21 (110)	0.519	0.538
U	—	—	—	1.39 (126)	.550	.514
B	—	—	—	1.39 (126)	.636	.600
C	—	—	—	1.10 (100)	.494	.547

[a] C=control, AN=ammonium nitrate, U=urea, B=biuret.
[b] Covariate = 1983 (initial) bole volume.

We expected that biuret might promote tree growth by retarding growth of competing vegetation; however, we observed no foliage discoloration or depressed growth of any native plants, including locally prevalent salal (*Gaultheria shallon*), Oregongrape (*Berberis* sp.), and bracken fern (*Pteridium aquilinum* (L.) Kuhn.). Hence, 224 kg N/ha as nearly pure biuret was not toxic to these native plants and associated Douglas-fir during our 8-year period of observations. Prescott and Weetman (1994) summarize previously published and nonpublished observations of reductions in salal density in N-fertilization trials in Washington and British Columbia. Reductions of salal cover are attributed to shading from denser crowns on N-fertilized plots and after dosages of 600 kg N/ha, or more as urea or AN, to high concentrations of ammonium and nitrate in the forest floor and soil. Anderson[4] showed an obvious contrast of full salal cover immediately outside the plot boundary compared to complete absence of salal within a plot fertilized with 536 kg N/ha as urea 11 years earlier. A neighboring plot fertilized with 357 kg N/ha had less than 50 percent cover of salal compared to full cover on the adjacent unfertilized plot. These observations on a gravelly outwash site near Shelton, Washington, support the explanation that fertilization with about 600 kg N/ha or more can have a toxic salt-effect that is independent of concomitant increased shading from the tree canopy. The 200 kg N/ha applied at our study site was probably insufficient to provide toxic concentrations of ammonium and nitrate from any of the N-sources tested. Hence, the salal and other species in our study area were not visually affected at the applied dosage.

[4] Personal communication. 1971. Harry Anderson, soil scientist, Washington Department of Natural Resources, Olympia, WA.

Within the mixed stand, adjusted response to N-fertilization was minimal (10 percent with biuret and zero with AN and urea) and statistically nonsignificant. Nearly pure biuret was the only N-source that seemed to stimulate growth within the mixed stand, but we have no explanation for this or for the result on both east and west sides that biuret was more effective than urea within the mixed stand and less effective at 60 m. The strong response to fertilization at 15 m and farther from the mixed stand indicated that red alder is not providing sufficient N for improved Douglas-fir growth at 15 m or greater distance.

Conclusions

Eight years after Douglas-fir trees were fertilized with ammonium nitrate, urea, or reagent-grade biuret, volume growth of dominant and codominant trees at this N-deficient location was increased by about the same amount by all three N-sources. Although response to more soluble ammonium nitrate was slightly faster than response to urea and biuret, continued preference for the cheapest N-source, urea, is justified.

Volume growth of nonfertilized Douglas-fir declined with distance from the mixed stand of red alder and Douglas-fir, and 8-year response to fertilizers on the west side increased linearly with distance from N-fixing red alder. East of the mixed-species strip, however, response was not related to distance.

Biuret had no apparent toxic effect on competing vegetation in the 8 years after fertilization.

Acknowledgments

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Metric Equivalents

When you know	Multiple by	To find
Centimeters (cm)	0.394	Inches
Meters (m)	3.281	Feet
Hectares (ha)	2.471	Acres
Cubic meters (m^3)	35.315	Cubic feet
Kilograms (kg)	2.205	Pounds

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At a nitrogen-deficient site in southwest Washington, we (1) compared effects of ammonium nitrate, urea, and biuret on volume growth of dominant Douglas-fir and (2) determined how 8-year response of these trees to fertilization related to their distance from a strip of Douglas-fir plantation interplanted with nitrogen-fixing red alder. Volume growth related linearly and positively to initial tree volume. Adjusted mean volume growth increased by 22 to 28 percent on the east side and by 11 to 14 percent on the west side, with no significant difference in response to the three fertilizers.

Keywords: *Pseudotsuga menziesii*, Douglas-fir, *Alnus rubra*, red alder, nitrogen fertilization, biuret, ammonium nitrate, urea, volume growth.

Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, Oregon 97208-3890

U.S. Department of Agriculture
Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, Oregon 97208-3890